222022

UCRL-JC-110348
PREPRINT

Dynamic Underground Stripping Engineering Demonstration Project: Construction, Operation, and Engineering Results

William H. Siegel
Mike Buettner
Kent Udell

This paper was prepared for submittal to the
Spectrum 92
Boise, Idaho
August 23-27, 1992

May 1992

Lawrence Livermore National Laboratory

DISCLAIMER

DYNAMIC UNDERGROUND STRIPPING ENGINEERING DEMONSTRATION PROJECT: CONSTRUCTION, OPERATION AND ENGINEERING RESULTS

W. H. Siegel and H. M. Buettner
Lawrence Livermore National Laboratory[a]
P.O. Box 808
Livermore, California 94550
(510) 422-0390

K. S. Udell
University of California
6165 Etcheverry Hall
Berkeley, California 94720
(510) 642-2928

ABSTRACT

The Dynamic Underground Stripping Project demonstrates cost-effective, rapid cleanup of localized underground plumes, often the result of leaking underground storage tanks. The technique combines the complementary technologies of subsurface steam injection and electrical resistance heating.

The engineering demonstration phase of this project was completed on a clean, uncontaminated site with well-characterized geology.[1,2] The Clean Site is located in Livermore, California at the U.S. Department of Energy's Sandia National Laboratory (SNL). The experience gained at the Clean Site, will be applied to clean up an 8,000 to 12,000 gallon gasoline spill, approximately 500 yards to the northwest, at the Lawrence Livermore National Laboratory (LLNL).

DYNAMIC UNDERGROUND STRIPPING

Dynamic underground stripping is an integrated process combining the complementary technologies of steam injection and electrical resistance heating. Steam injected through multiple wells on the perimeter of a plume volatilizes the contaminants in permeable zones and sweeps them towards a central vacuum-liquid extraction well.[3,4] Electrical resistance heating volatilizes contaminants in low permeability clay zones not penetrated by the steam.[5] Current passes through the ground between electrodes installed in the perimeter wells. As the clay regions are heated, volatile contaminants are driven into the permeable zones, where they are removed by vacuum extraction or subsequent steam floods.

Fielding these techniques poses technical and operational challenges. An uncontaminated site was selected for the engineering demonstration to solve the engineering problems. Two test patterns were built: a large-scale steam injection pattern was built on the scale of the gasoline-contaminated site at LLNL, and a small-scale pattern was used for electrical heating.[6]

LARGE-SCALE PATTERN WELL CONSTRUCTION

The following wells were included in the large-scale pattern: 11 combination temperature-tomography wells, 3 geophysical monitoring wells, 2 extraction wells, 1 steam injection well, and 3 piezometer wells. Figure 1 shows the location of each well and its type. Figures 2 through 4 are typical completion drawings for some of the wells in the large-scale pattern.

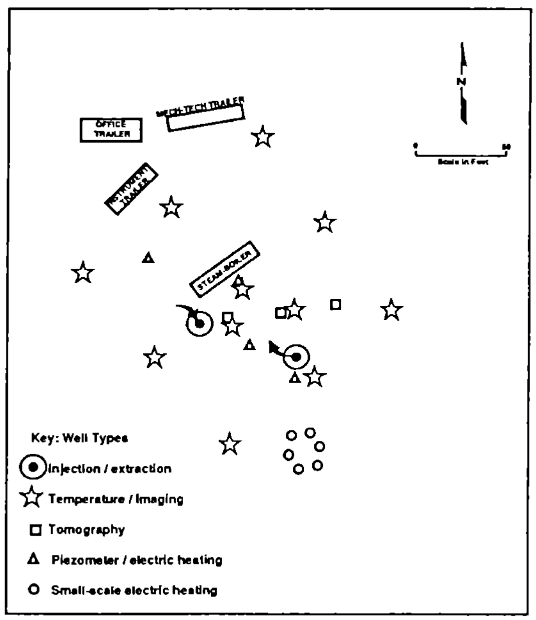

Figure 1. Clean Site wells.

[a]This work was funded by the Office of Technology Development of the U. S. Department of Energy. Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract number W-7405-Eng-48.

STEAM INJECTION AND EXTRACTION: OPERATIONS AND RESULTS

Steam injection operations were conducted 24 h/d for 26 days; the steam was generated by a 200-hp Cleaver Brooks Mobile Steam Plant. During the steam injection operation, 295,000 gallons of steam were injected into the ground at an average rate of 8.5 gal/min (4200 lb/h). Approximately 10,000 yd^3 of soil were raised to the boiling point of water. Figure 5 presents steam injection operational statistics.

Geophysical imaging showed that steam movement was primarily oriented towards the extraction well and gradually expanded to a 270° arc around the injection well.[7–12] Although this result may have been influenced by vacuum-liquid extraction during the first 10 days of operation, a more likely cause is variable permeability in the target gravel layer. Steam breakthrough to the extraction well, which occurred approximately four days after the start of injection, is reflected in the plot of extracted water temperature in Fig. 5.

Injection pressure was limited to 0.5 psi/ft of overburden to eliminate the possibility of fracturing the ground to the surface and venting steam.[13] The injection interval was from 135 to 155 ft at the Clean Site, which dictated an injection pressure of less than 78 psi. A conservative injection pressure of 50 psi was selected for the first four days of operation. During the test the pressure was gradually increased from 50 to 70 psi. During the last three days of injection, the boiler began to cycle off and on as the

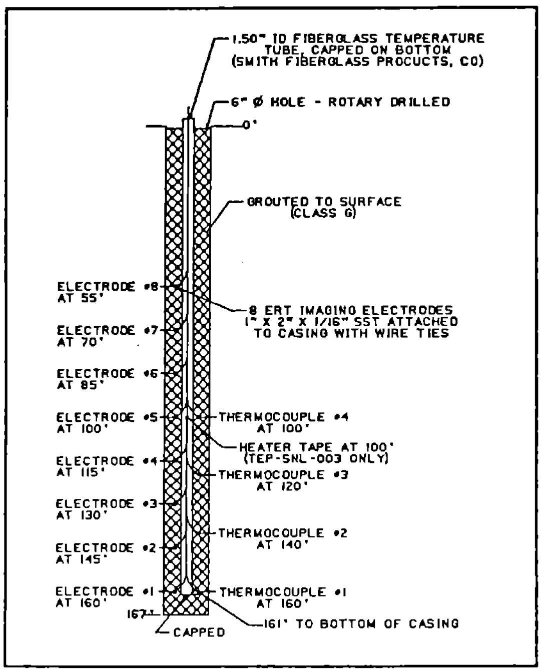

Figure 2. Temperature-Tomography well.

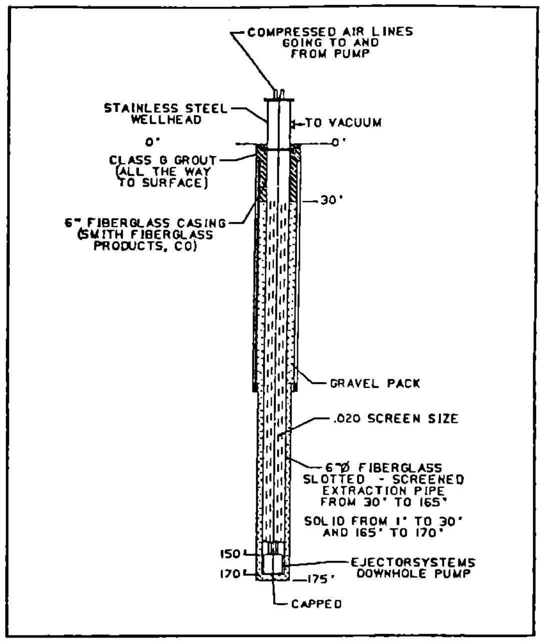

Figure 3. Extraction well.

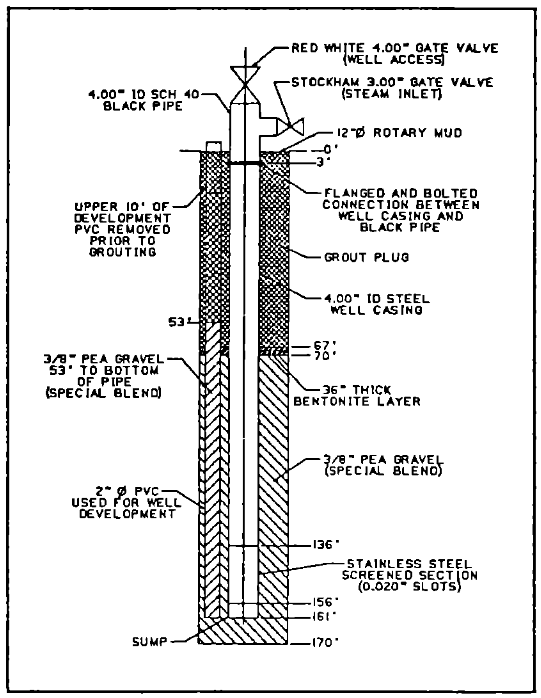

Figure 4. Steam injection well.

demand for steam diminished (see Fig. 5). This cycling suggests steam saturation of the permeable zones near the injection well.

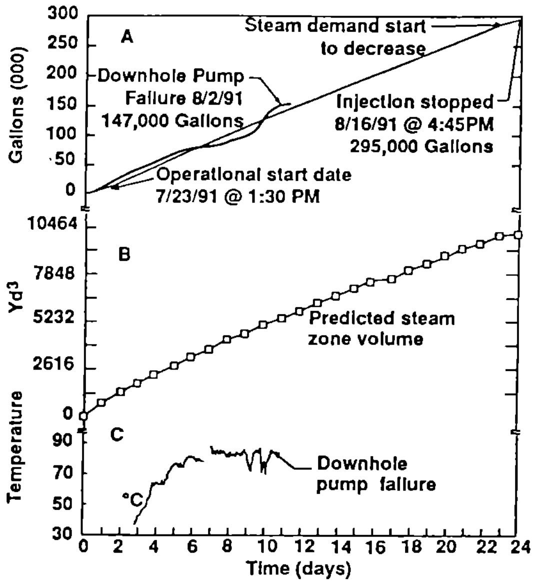

Figure 5. Clean Site steam injection operational statistics. A)Steam injected as water and extracted water volume. B)Total volume of steamed subsurface. C) Extracted ground water temperature.

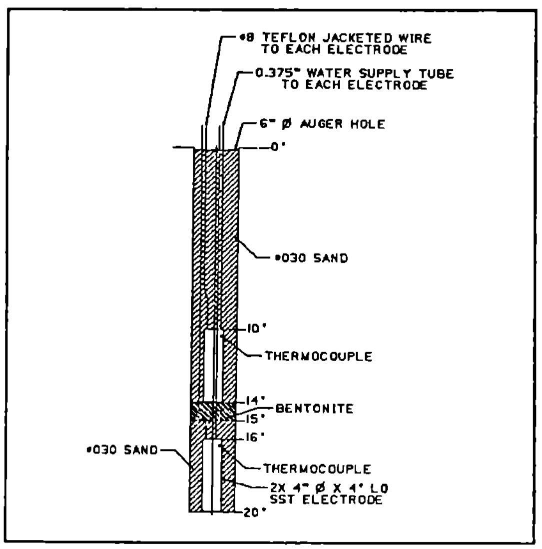

Figure 6. Typical electrical heating well design for Test 1. Note the use of sand as an electrode packing material for the six wells in the test.

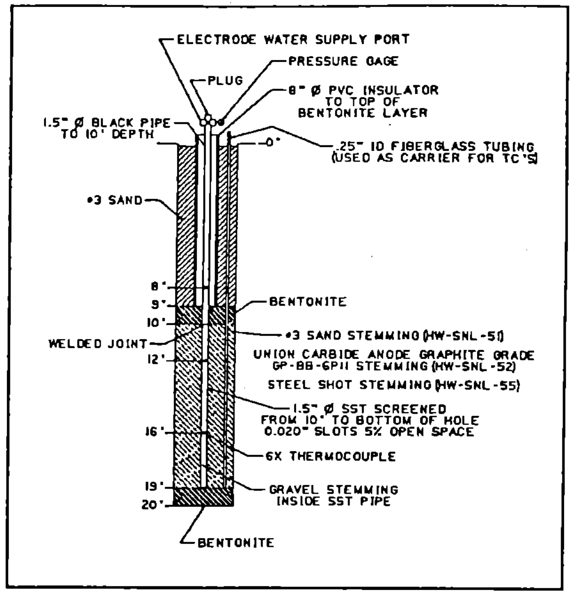

Figure 7. Typical electrical heating well design for Tests 2 and 3. Electrode packing material consisted of sand, steel shot, or anode graphite.

SMALL-SCALE PATTERN WELL CONSTRUCTION

We drilled seven electrical heating holes and 10 temperature holes in the small-scale electrical heating pattern. The holes were a maximum of 20 ft deep with a diameter of 4 to 8 in; the heating wells were equally spaced on a 20-ft-diam circle. Figures 6 and 7 display typical completion drawings for the small-scale wells.

SMALL-SCALE ELECTRICAL HEATING: OPERATIONS AND RESULTS

Three small-scale electrical heating tests were conducted to evaluate the effects of moisture content and completion materials around each electrode, as well as electrode power density. We found that conductance into the formation was greatly affected by moisture content around the electrodes. Amperage levels were high when the soil was moist and gradually dropped as the area around the electrode heated and dried. We were able to control the amperage levels somewhat by selectively wetting electrodes with lower current values. However, we achieved better control by regulating generator output voltage.

The first heating experiment (Test 1) was conducted with a three-phase, 72-kW generator operated at 480 V. The test was conducted for 15 days (11 days running 24 h/d and 4 days running 12 h/d). Sand completion material was used around all of the electrodes.

During the two-week test, the temperature in the center of the 20-ft-diam pattern increased from 19°C to 38°C (1.6°C/d) during the 24-h/d heating, to 44°C during day-only heating, and finally to 54°C at the end of 25 days. Figure 8 shows a plot of the temperature change at the center of the pattern. During Test 1, the electrode packing material had to be wet continuously from water reservoirs at the surface to maintain conductivity. The average current per phase was 73 A during 24-h/d heating.

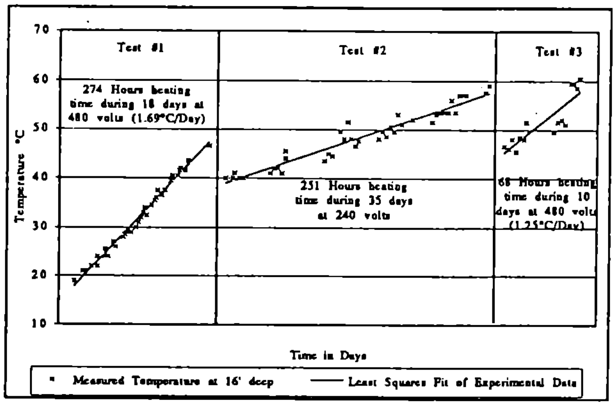

Figure 8. Temperature change at the center of the small-scale electrical heating pattern for the three electrical heating tests.

The second small-scale test was operated at 240 V. Test 2 ran 12 h/d for 44 days. The electrode configuration was changed from the individual electrode design used in Test 1 (Fig. 6) to continuous mild steel casings from the surface to the injection point (Fig. 7). Steel shot or anode graphite replaced the sand completion material around four of the electrodes. Amperage levels for the electrodes in the steel shot and graphite wells remained consistently higher than in wells completed with sand. The average current per phase varied from 44 A, for phases with electrodes packed in sand, to 60 A for phases with electrodes packed only in steel shot or graphite. To maintain conductivity into the formation, electrodes packed with graphite or steel shot required minimal wetting, at most only once per day.

During Test 2, the temperature at the center of the pattern increased from 40°C to 54°C; the rate of temperature change was 0.54°C/d. The lower heating rate of this test (compared with Test 1) reflects the applied voltage of 240 V versus 480 V and heating for 12 h/d instead of 24 h/d.

Test 3 used a three-phase, 100-kW generator with an applied voltage of 480 V. The electrode design and well completion materials were the same as in Test 2; however only three of the six wells were used. The test was conducted for 12 h/d for five days. The temperature at the center of the pattern increased a total of 12°C; the average daily heating rate was 1.25°C. The average current per phase during Test 3 varied from 135 A for phases with electrodes packed in sand to 139 A for phases with electrodes packed only in steel shot or graphite.

We found that generally electrodes packed in steel shot or graphite maintained higher amperage levels with less frequent wetting requirements than electrodes packed in sand. From an operating standpoint, Tests 2 and 3 required much less maintenance and monitoring.

SITE SAFETY

Personnel safety was a primary factor during the construction and operation phases of the engineering demonstration. LLNL Operational Safety Procedures (OSPs) included hazards analysis, personnel training, and protective clothing requirements, and operation controls applicable to each activity. We established procedures for steam injection, electrical heating, and piezometer well measurements. Calculations supporting the hazards analysis were documented in LLNL Safety Notes.

One additional OSP, written after the engineering demonstration began, established maintenance procedures on wells or downhole equipment (e.g., pumps), where underground steam is present. Experience at the Clean Site has shown that when the wells are opened, they can discharge hot water and steam through the wellhead, creating a geyser. We eliminated this geyser by quenching the well with cold water from the surface.

REGULATORY REQUIREMENTS

We encountered a number of regulatory issues throughout the engineering demonstration. Some of the agencies involved included the San Francisco Bay Area Air Quality Management District (BAAQMD), the Regional Water Quality Control Board (RWQCB), the U.S. Occupational Safety and Health Administration (OSHA), the U.S. Environmental Protection Agency (EPA), and city and county agencies. Specific issues included:

- Requirements of the Bay Area Air Quality Management District for boiler and electrical generator emissions. Because of strict air quality regulations in the Bay Area, sources that discharge more than 5 lb/d of NO_x emissions are required to use best available control technology (BACT) such as flue gas recirculation and low NO_x burners.

- Requirements of the Regional Water Quality Control Board for the construction and use of injection and monitoring wells. Wells drilled in the public right-of-way were also subject to approval from city and county agencies.

- Approval from local water treatment facilities to dispose of boiler blowdown and brine solutions into the sanitary sewer.

- Requirements of state and federal agencies, such as OSHA and the EPA, for storage of hazardous waste resulting from well construction and extracted effluent.

LESSONS LEARNED

The engineering demonstration led to the following changes:

- An improved operational strategy. Our original plan called for steam injection followed by electrical heating. We assumed that the resistivity contrast between the permeable and impermeable layers would be greater after steam injection. In fact, the opposite was true. Because of the rise in temperature in the permeable layers, the contrast in resistivities actually became smaller, resulting in inefficient dissipation of electrical energy into both zones. On the basis of these results, electrical heating will be conducted first at the gasoline-contaminated site at LLNL.
- Larger-diameter casing to accommodate the deformation caused by higher subsurface temperatures. Some of the 1.5-in fiberglass casings were deformed to a slightly oblate cross section, preventing passage of logging tools. A nominal 2-in-diam casing will be used at the gasoline-contaminated site to eliminate this problem. We successfully used fiberglass casings in the wells despite subsurface temperatures slightly in excess of the fiberglass temperature rating.
- Using threaded adaptors bonded to the ends of fiberglass pipes. At the Clean Site, we bonded fiberglass casings together over the hole as they were installed. Each bonded joint required approximately 30 min of cure time before going downhole. Using threaded adaptors provides two advantages: a more controlled bonding process because it can be completed long before installation and a significant reduction in drill-rig time required to install the casing.
- Quenching the extraction well solved the geyser problem. Extraction well pump maintenance during steam injection posed a personnel safety problem. With the wellhead open, the well acted like a geyser, creating hazardous working conditions. Injecting cold water into the well from the surface quenched the well and made it possible to work safely around the wellhead. A new OSP was developed for use at the Gas Pad.
- A more robust, damage-tolerant electrode design was developed and tested in Electrical Heating Tests 2 and 3. The new design, which uses steel casings as the electrical connection from the electrode to the surface, will be implemented at the LLNL gasoline-contaminated site.
- Using alternate electrode stemming materials such as steel shot or graphite increased conductance into the formation.
- More flexible voltage control will be used at LLNL to accommodate variations in electrode conductance caused by the moisture content of the surrounding soil.

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